POST-TENSIONING.

(REV 6-27-01) (FA 7-9-01) (1-02)

PAGE 620. The following new Section is added after Section 460:

SECTION B460
POST-TENSIONING

B460-1 Description.

Furnish, install, stress and grout prestressing tendons. Install prestressing steel, which may be strands, wires or bars, through preformed voids or ducts in the concrete or in external ducts, stress to a predetermined load and anchor directly against the hardened concrete, initially imparting stresses through end bearing. Then inject grout into the ducts to completely fill all remaining voids and to seal the permanently stressed tendons.

Furnish and install all hardware and any other appurtenant items necessary for the particular prestressing system used, including but not limited to ducts, anchorage assemblies, supplementary steel reinforcing bars and grout used for pressure grouting ducts and all associated operations.

Submit shop and working drawings and manuals in accordance with Section 5.

B460-2 Terminology.

Post-Tensioning: The application of a compressive force to the concrete by stressing tendons or bars after the concrete has been cast and cured. The force in the stressed tendons or bars is transferred to the concrete by means of anchorages.

Post-Tensioning Scheme or Layout: The pattern, size and locations of post-tensioning tendons provided by the Designer on the Contract Plans.

Post-Tensioning System: A proprietary system where the necessary hardware (anchorages, wedges, strands, bars, couplers, etc.) is supplied by a particular manufacturer or manufacturers of post-tensioning components.

Duct: Material forming a conduit to accommodate prestressing steel installation.

Tendon: A high strength steel member made up of a number of strands, wires or bars.

Strand: An assembly of several high strength steel wires wound together. Strands usually have six outer wires helically wound around a single straight wire of a similar diameter.

Wire: A single, small diameter, high strength steel member and, normally, the basic component of strand, although some proprietary post-tensioning systems are made up of individual or groups of single wires.

Bar: Post-tensioning bars are high strength steel bars, normally available from 5/8 to 1 3/8 inch [15 to 36 mm] diameter and usually threaded with very coarse thread.

Coupling: The means by which the prestressing force may be transmitted from one partial - length prestressing tendon to another.

Anchorage: An assembly of various hardware components which secure a tendon at its ends after it has been stressed and imparts the tendon force into the concrete.

Anchor Plate: That part of the anchorage that bears directly on the concrete and through which the tendon force is transmitted.

Wedges: A small conically shaped steel component placed around a strand to grip and secure it by wedge action in a tapered hole through a wedge plate.

Wedge Plate: A circular steel component of the anchorage containing a number of tapered holes through which the strands pass and are secured by conical wedges.

Set (Also Anchor Set or Wedge Set): Set is the total movement of a point on the strand just behind the anchoring wedges during load transfer from the jack to the permanent anchorages. Set movement is the sum of slippage of the wedges with respect to the anchorage head and the elastic deformation of the anchor components. For bars, set is the total movement of a point on the bar just behind the anchor nut at transfer and is the sum of slippage of the bar and the elastic deformation of the anchorage components.

Anticipated Set: Anticipated set is that set which was assumed to occur in the design calculation of the post-tensioning forces immediately after load transfer.

B460-3 Alternate Post-Tensioning Designs.

Alternate designs using a post-tensioning scheme other than that shown on the plans may be submitted for the Engineer’s approval provided that the proposed alternate scheme fulfills the following requirements:

(1) The prestress system is a type described in B460-4.

(2) The net compressive stress in the concrete after all losses is at least as large as that provided by the scheme shown on the Plans.

(3) The distribution of individual tendons at each cross-section generally conforms to the distribution shown on the Plans.

(4) The ultimate strength of the structure with the proposed post-tensioning scheme meets the requirements of either Section 9 of the AASHTO Standard Specifications for Highway Bridges or Section 5 of the AASHTO LRFD Bridge Design Specifications, whichever is required by the Contract Plans, and shall be equivalent to the ultimate strength provided by the original design.

(5) Stresses in the concrete and prestressing steel at all sections and at all stages of construction meet the requirements of the Design Criteria noted on the Plans.

(6) All provisions of the Design Criteria noted on the Plans shall be satisfied.

(7) The Contractor fully redesigns and details, as required, the elements where the alternate post-tensioning scheme is proposed to be used.

(8) The Contractor submits complete shop drawings including post-tensioning scheme and system, reinforcing steel, and concrete cover; and design calculations (including short and long term prestress losses) for the Engineer’s approval.

(9) Any alternate post-tensioning scheme or system approved by the Engineer, which results in a change in quantity from that shown on the plans, will be paid based on the quantity actually used and accepted or the plan quantity, whichever is less, and at the unit bid price. If the approved alternate post-tensioning scheme or system is under a VECP (Value

Engineering Change Proposal), the method of payment will be in compliance with the VECP agreement.

B460-4 Materials.

B460-4.1 Prestressing Material:

B460-4.1.1 Prestressing Steel:

(a) Strand: Unless otherwise noted on the plans, use uncoated, Grade 270 [1,860 MPa], low relaxation seven-wire strand meeting the requirements of ASTM A 416.

(b) Bar: Unless otherwise noted on the plans, bar shall be uncoated, Grade 150 [1,035 MPa], high strength, coarse thread bar meeting the requirements of ASTM A 722, Type II.

(c) Wires: Unless otherwise noted on the plans, use uncoated, low relaxation wire meeting the requirements of ASTM A 421.

The proper use of strand, bars and wires is predicated upon the use of suitable accessory materials. Furnish details from the manufacturer for the use of these materials in connection with shop and working drawing submittals.

B460-4.1.2 Bar and Tendon Couplers: For permanent applications, the use and location of bar and tendon couplers is subject to approval by the Engineer. Where bars are coupled, the assembled units shall develop at least 100% of the manufacturer's minimum specified ultimate tensile strength of the bar, tested in an unbonded state without exceeding the anticipated set. The coupling of tendons shall not reduce the elongation at rupture below the requirements of the tendon itself. Tendon couplers shall develop at least 100% of the minimum ultimate tensile strength of the tendon.

B460-4.1.3 Prestress Anchorages: Secure all prestressing steel at the ends by anchoring devices approved by the Engineer. Only anchorages which are accessible after the concrete hardens will be allowed for use with prestressing strand. The anchorages shall develop at least 100% of the minimum specified ultimate tensile strength of the prestressing steel, tested in an unbonded state without exceeding the anticipated set. Supply certified copies of test results for the anchorage system to the Engineer at no additional cost. The anchorage shall be so arranged that the prestressing force in the tendon may be verified prior to removing the stressing equipment.

The Engineer will immediately stop the use of two part wedges that show any sign of slippage or failure to grip the tendon without exceeding the anticipated set, and require the use of acceptable alternative three part wedges for anchoring post-tensioning strands at no additional cost to the Department.

The anchoring devices shall effectively distribute tendon forces to the concrete and meet the following requirements:

(a) The average bearing stress in the concrete created by the bearing plate shall not exceed the values as determined by the following equations:

At service load:

$$f_{cp} = 0.6\, f`_c /(A'_b/A_b)$$

but not greater than 1.25 f'_c

At transfer load:

$$f_{cp} = 0.8\, f'_{ci} /[(A'b/Ab)!0.2]$$

but not greater than $1.25\, f'_{ci}$

Where: f_{cp}= Permissible concrete compressive stress

f'_c= Compressive strength of concrete (28 days)

f'_{ci}= Compressive strength of concrete at time of initial prestress (transfer).

A'_b= Maximum area of the portion of the concrete anchorage surface that is geometrically similar to and concentric with the area of the anchorage.

A_b= Bearing area of the anchorage.

Limit the stresses calculated at application of the post-tensioning force and at service load to 5,000 and 6,250 psi [35 and 43 MPa], respectively, as absolute maximum values, even if the concrete strength is in excess of 4,000 psi [27 MPa] at transfer (load application) and/or 5,000 psi [35 MPa] at 28 days.

(b) Bending stresses in the plates or assemblies induced by the pull of the prestressing steel shall not exceed the yield point of the material or cause visible distortion of the anchorage plate when 100% of the ultimate strength of the tendon is applied. Provide the Engineer certified test reports from an approved independent testing laboratory, verifying compliance with this requirement, for each type and/or size of anchoring device.

Anchorage devices not meeting with either or both of the above requirements [(a) and (b)] may be accepted based upon previously approved usage in the State of Florida or on the basis of new or previous tests performed in accordance with and meeting the requirements of the 1989 AASHTO Guide Specifications for the Design and Construction of Segmental Concrete Bridges, Division II, Section 4.2 “Special Anchorage Devices”, all at no cost to the Department. In such cases, incorporate any additional confinement reinforcement or modifications to existing reinforcement required for satisfactory performance of the anchorage devices in the structure at no additional cost to the Department.

B460-4.1.4 Ducts:

B460-4.1.4.1 General: Unless specifically noted on the Plans or otherwise approved by the Engineer, use ducts for post-tensioning meeting the requirements of this Specification.

For ducts embedded in the concrete for prestressing steel use either galvanized ferrous metal, or high density virgin polyethylene. However, high density virgin polyethylene will not be allowed at locations where galvanized ferrous metal is designated on the plans, or when the radius of curvature is less than 30 feet [9 m].

Ducts shall be sufficiently rigid to withstand concrete placement, grouting and construction loads without damage or excessive deformation, while remaining water-tight.

B460-4.1.4.2 Size of Ducts: Ducts for multi-strand, multi-bar or multi-wire tendons shall have a minimum size which provides an inside area at least 2.5 times the net area of the prestressing steel. Ducts for single strand, single bar or single wire tendons shall have an inside diameter at least 3/8 inch [10 mm] larger than the nominal diameter of the strand, bar or wire.

B460-4.1.4.3 Ferrous Metal Ducts: Ferrous metal ducts shall be galvanized. Rigid metal ducts may be fabricated with either welded or interlocked seams. Ducts shall bend without crimping or flattening and shall have sufficient strength to maintain their correct alignment during placing of concrete. Joints between sections of ducts shall have positive metallic connections which do not result in angle changes at the joints.

B460-4.1.4.4 Epoxy Coated Metal Ducts: Epoxy Coated Metal Ducts shall not be used.

B460-4.1.4.5 Polyethylene (P.E.) Ducts and Pipes: Ducts and pipes shall be sufficiently rigid to withstand concrete placement, grouting and construction loads without damage or excessive deformation, while remaining watertight.

Provide corrugated polyethylene ducts embedded in the concrete which meet the requirements of ASTM D3550 with a cell classification of 345433C and a minimum wall thickness of 0.08 ± 0.01 inch [2 ± 0.25 mm]. Provide rigid smooth walled polyethylene ducts used for external tendons which meet the requirements of ASTM D1248, Type III, Category 5, Grade P33 and an outside diameter to wall thickness ratio of 18 or less.

Plastic material used shall not react with concrete or enhance corrosion of prestressing steel and shall be free of water soluble chloride.

Smooth pipes shall not be used in locations embedded in the concrete. Smooth pipes are acceptable for use with external tendons.

Ducts, pipes and all connections shall be capable of withstanding the pressure required for flushing the ducts in the event of an aborted grouting operation.

B460-4.1.4.6 Steel Pipes: Where called for on the Plans, steel pipes shall conform to ASTM A 53, Grade B Schedule 40. In extremely aggressive environments, the steel pipes shall be galvanized.

B460-4.1.5 Grout Vents, Injection and Ejection Pipes: Provide vents made of standard pipe or suitable plastic pipe with a minimum diameter of 3/4 inch [20 mm] for strand tendons in round duct and 3/8 inch [10 mm] for single bar tendons and for strand tendons in oval ducts. Neither metallic nor plastic components, if selected and approved, shall react with the concrete or enhance corrosion of the prestressing steel. Use plastic components free of water soluble chlorides.

Provide grout injection pipes fitted with positive mechanical shut-off valves. Provide vents and ejection pipes fitted with valves or other devices capable of withstanding the grout pumping pressures.

B460-4.1.6 Grout: Use grouts meeting the requirements of Section 938 to grout all post-tensioning systems.

B460-4.2 Samples for Testing:

B460-4.2.1 General: Testing shall conform to the applicable ASTM Specifications for the prestressing material used.

Furnish all material samples for testing at no cost to the Department.

Consider the job site or site referred to herein as the location where the prestressing steel is to be installed, whether at the bridge site or a removed casting yard.

B460-4.2.2 Prestressing Steel and Components: Furnish samples for testing as described below for each manufacturer of prestressing strand, bar, wire, bar and/or tendon couplers, and anchorage assemblies to be used on the project.

With each sample of prestressing steel strand, bars or wires furnished for testing submit a certification stating the manufacturer’s minimum guaranteed ultimate tensile strength of the sample furnished.

Allow the Engineer to sample the following materials, selected by the Engineer at the plant or jobsite, from the prestressing steel used for post-tensioning operations well in advance of anticipated use:

(a) For strand: One randomly selected sample, 5 feet [1.5 m] long, per manufacturer, per size of strand, per shipment, with a minimum of one sample for every ten reels delivered.

(b) For bars: Three randomly selected samples, 5 feet [1.5 m] long, per manufacturer, per size of bar, per heat of steel, with a minimum of one sample per shipment.

(c) For wire: One randomly selected sample, 5 feet [1.5 m] long, per manufacturer, per size of wire, per heat of steel, per shipment, with a minimum of one sample for every ten coils delivered.

(d) For permanent couplers: Three units of 2 foot [0.5 m] lengths of bar/tendon, each equipped with one coupler and fabricated to fit the coupler, per manufacturer, per heat of coupler steel.

(e) For anchorage assemblies: Two samples of each size, per manufacturer, per heat of steel.

One of each of the samples furnished to represent a lot will be tested. The remaining sample(s), properly identified and tagged, will be stored by the Engineer for future testing in the event of loss or failure of the component represented to meet minimum strength requirements. For acceptance of the lot represented, test results must show that 100% of the guaranteed ultimate tensile strength has been met.

B460-4.2.3 Lots and Identification: A lot is that parcel of components as described herein. All bars, anchorage assemblies and couplers of each size from each mill heat of steel, all wire from each manufactured coil and all strand from each manufactured reel to be shipped to the site shall be assigned an individual lot number and shall be tagged in such a manner that each such lot can be accurately identified at the job site. Submit records to the Engineer identifying assigned lot numbers with the heat, coil or reel of material represented. All unidentified prestressing steel, anchorage assemblies or bar couplers received at the site will be rejected. Also, loss of positive identification of these items at any time will be cause for rejection.

B460-4.3 Release of Materials: The release of any material by the Engineer shall not preclude subsequent rejection if the material is damaged in transit or later damaged or found to be defective.

B460-5 Testing by the Contractor (Not Required on Post-tensioned, Precast Slab Unit Bridges and Double Tee Bridges).

B460-5.1 Tendon Modulus of Elasticity: This test will not be required if the Contractor can demonstrate to the satisfaction of the Engineer, valid results for the tendon modulus of elasticity from previous projects. Such results must be for the same type of strand, size, material and complement of strands per tendon as required for this project and must have been performed under test conditions equal to or better than those described below.

For the purpose of accurately determining the tendon elongations while stressing, the Contractor shall bench test two samples of each size and type of tendon to determine the modulus of elasticity prior to stressing the initial tendon.

For the purpose of this test, the bench length between anchorages shall be at least 40 feet [12 m] and the tendon duct shall be at least 2 inches [50 mm] clear of the tendon all around. The test procedure shall consist of stressing the tendon at an anchor assembly with a load cell at the dead end. Tension the test specimen to 80% of ultimate in ten increments and then detention from 80% of ultimate to zero in ten decrements. For each increment and decrement, record the gauge pressure, elongations and load cell force. Note elongations of the tendon for both ends and the central 30 feet [9 m], measured to an accuracy of ±1/32 inch [±1 mm]. Correct the elongations for the actual anchorage set of the dead end.
Calculate the modulus as follows:

$$E = \frac{PL}{Adl}$$

where;

P= force in tendon,

L= distance between pulling wedges and dead end wedges or exact length in center 30 feet [9 m] of the tendon.

A= cross-sectional area of the tendon based on nominal area.

dl= strand elongation for load P.

Reevaluate and correct the theoretical elongations shown on the post-tensioning shop or working drawings using the results of the test when the modulus of elasticity from the bench test varies from the modulus of elasticity used for the shop or working drawings by more than 1%. Submit revisions to the theoretical elongations to the Engineer for approval.

When the observed elongations of the tendons in the erected structure fall outside the acceptable tolerances or to otherwise settle disputes, additional Tendon Modulus of Elasticity Tests may be required to the satisfaction of the Engineer.

If the source of prestressing steel changes during the project, additional test series or substantiation from previous projects, not to exceed two per source shall be required.

The apparatus and methods used to perform the test must be submitted to the Engineer for approval. Tests shall be conducted in the Engineer’s presence.

B460-5.2 In Place Friction Test: This test is intended to demonstrate that the friction characteristics, losses and resulting tendon forces are in agreement with the design assumptions.

For the purpose of verifying friction loss the Contractor shall test in place, the first draped or horizontally curved tendon installed of each size and type which is at least 50 feet [15 m] long. Size is defined as the size and number of strands, bars or wires in each tendon. Type is defined as to both prestressing and duct material and to the tendon function within the structure. Function is the general category of the tendon whether it is a cantilever tendon, continuity tendon, draped external tendon or continuous profiled tendon passing through one or more spans, etc. In this respect, the function of two or more tendons may be the same even though their actual profiles and lengths differ. The in place friction test is not required on small projects with straight tendons (for example, straight transverse tendons in flat slabs or precast units).

The test procedure shall consist of stressing the tendon at an anchor assembly with a load cell at the dead end. Tension the test specimen to 80% of ultimate tendon strength in eight equal increments and detention in eight equal decrements. For each increment and decrement, record the gauge pressure, elongations and load cell force. Take into account any wedge seating in both the live end (i.e., back of jack) and the dead end (i.e., back of load cell) and of any friction within the anchorages, wedge plates and jack as a result of slight deviations of the strands through these assemblies. For long tendons requiring multiple jack pulls with intermediate temporary anchoring, keep an accurate account of the elongation at the jacking end allowing for intermediate wedge seating and slip of the jacks' wedges.

Conduct the test using the lubricants required, if any, to meet the expected friction coefficient.

If the elongations fall outside the ±5% range of the expected friction coefficients, assume responsibility to investigate the reason and make revisions to post-tensioning operations so the final tendon forces are in agreement with the Plans.

In reconciling theoretical and actual elongations, do not vary the value of the expected friction and wobble coefficients by more than ±10%. Significant shortfall in elongations is indicative of poor duct alignments and/or obstructions. Correct or compensate for such elongations in a manner proposed by the Contractor and reviewed and approved by the Engineer at no additional cost to the Department.

The Engineer will require one successful friction test for each type and size of tendon for the project.

If there are irreconcilable differences between forces and elongations, or other difficulties during the course of routine stressing operations, the Engineer may require additional in place friction tests.

The apparatus and methods used to perform the test must be submitted to the Engineer for approval. Tests shall be conducted in the Engineer's presence.

Ensure that the originator of the stressing and elongation calculations assumes responsibility for correction or adjustment of elongations from friction test results.

B460-5.3 Tendon Dynamic Tests: When required by the Plans, the Contractor shall perform, on a representative specimen, a dynamic test for unbonded tendons and tendons which are grouted in ducts external to the concrete. The tendon shall withstand, without failure: 500,000 cycles from 60 to 66% of its minimum specified ultimate strength, and also: 50 cycles from 40 to 80% of its minimum specified ultimate strength.

One cycle involves the change from the lower stress level to the upper stress level and back to the lower. The specimen used for the second dynamic test need not be the same as used for the first dynamic test. When approved by the Engineer, post-tensioning systems utilizing multiple strands, wires, or bars may be tested using a test tendon of smaller capacity than the full size tendon. The test tendon shall duplicate the behavior of the full size tendon and generally shall not have less than 10% of the capacity of the full size tendon. Dynamic tests are not required on bonded tendons, unless the anchorage is located or used in a manner that repeated load applications can be expected at the anchorage.

One unbonded dynamic test shall be performed for each tendon system (multiple strands, wires or bars) prior to use. This test shall be conducted by a testing laboratory employed by the Contractor and approved by the Engineer.

B460-5.4 Tests Reports Required: Submit two test reports of the "Tendon Modulus of Elasticity Test" to the Engineer at least 30 days prior to installing the tendon.

Submit two test reports of the "In Place Friction Test" to the Engineer within two weeks after successful installation of the tested tendon.

Furnish two certified copies of the "Unbonded Tendon Dynamic Test" to the Engineer at least 30 days prior to installing any unbonded tendons in the structure.

B460-5.5 Payment for Testing: Testing by the Contractor will not be paid for separately but shall be incidental to the price paid for the post-tensioning.

B460-5.6 Application of Test Results: Reevaluate the theoretical elongations shown on the post-tensioning shop or working drawings using the results of the tests for Tendon Modulus of Elasticity and In Place Friction as appropriate and correct as necessary. Submit revisions to the theoretical elongations to the Engineer for approval.

B460-6 Protection of Prestressing Steel.

B460-6.1 Shipping, Handling and Storage: Protect all prestressing steel against physical damage and corrosion at all times from manufacturer to final grouting or encasing in the concrete. The Engineer will reject prestressing steel that has sustained physical damage at any time. Carefully inspect any reel that is found to contain broken wires during use and remove and discard lengths of strand containing broken wires. The wire shall be bright and uniformly colored, having no foreign matter or pitting on its surface.

Prestressing steel shall be packaged in containers or shipping forms for protection of the steel against physical damage and corrosion during shipping and storage. A corrosion inhibitor which prevents rust or other results of corrosion shall be placed in the package or form, or shall be incorporated in a corrosion inhibitor carrier type packaging material, or when permitted by the Engineer, may be applied directly to the steel. The corrosion inhibitor shall have no deleterious effect on the steel or the concrete or bond strength of steel to concrete. Inhibitor carrier type packaging material shall conform to the provisions of Federal Specification MIL-P-3420. Immediately replace or restore packaging or forms damaged from any cause to the original condition.

The shipping package or form shall be clearly marked with a statement that the package contains high-strength prestressing steel, the care to be used in handling, and the type, kind and amount of corrosion inhibitor used, including the date when placed, safety orders and instructions for use. Specifically designate low relaxation (stabilized) strand per requirements of ASTM A 416. Strands not so designated will be rejected.

B460-6.2 During Installation in the Structure: When acceptable prestressing steel for post-tensioning is installed in the ducts after completion of concrete curing and if stressing and grouting are completed within seven calendar days after the installation of the prestressing steel, rust which may form during these seven days will not be cause for rejection of the steel. Post-tensioning steel installed, tensioned and grouted in this manner, all within seven calendar days, will not require the use of a corrosion inhibitor in the duct following installation of the prestressing steel.

For post-tensioning steel installed in ducts prior to concrete placement, the above time shall be reckoned from the day of first installation of the post-tensioning in the ducts.

Post-tensioning steel installed as above but not grouted within seven calendar days shall have an approved water soluble oil corrosion inhibitor (emulsified rust passivator) applied in the ducts and shall be subject to all the requirements in this Section pertaining to corrosion protection and rejection because of rust.

Immediately prior to grouting, thoroughly flush the water soluble oil from the ducts with water.

Within 30 calendar days after installing the post-tensioning steel, grout ducts in accordance with these Specifications. Except when approved by the Engineer in writing, failure to grout tendons within the 30 calendar days specified will result in stoppage of the affected work and no invoices will be processed for payment of that affected work.

B460-7 Fabrication.

B460-7.1 General: Accurately and securely fasten all post-tensioning anchorages, ducts, vent pipes, miscellaneous hardware, reinforcing bars, and other embedments at the locations shown on the Plans or on the approved Shop or Working Drawings or as otherwise approved by the Engineer.

B460-7.2 Ducts: Accurately align ducts and position at the locations shown on the Plans or according to the approved Shop or Working Drawings or as otherwise approved by the Engineer. Securely fasten all internal ducts in position at regular intervals not exceeding 30 inches [0.75 m] to prevent movement, displacement or damage from concrete placement and consolidation operations. Show the method and spacing of duct supports on appropriate Shop Drawings. Ensure that ducts for external tendons are straight between connections to internal ducts at anchorages, diaphragms and deviation saddles and are supported at intermediate locations or dampers according to the plans or approved shop drawings.

Ensure that all alignments, including curves and straight portions, are smooth and continuous with no lips, kinks or dents. This also applies to curves in pre-bent steel pipe.

Carefully check and repair all ducts as necessary before placing any further concrete.

After installing the forms, ensure that all ends of ducts, connections to anchorages, splices, vents and the like are sealed water-tight at all times to prevent the entry of water and debris.

B460-7.3 Splices and Joints: At splices and joints, and connections to anchorages, smoothly align and secure ducts with no lips or kinks. Join them in a way that positively prevents the entrance of cement paste and water from the concrete or unwanted leakage of grout during subsequent grouting operations.

B460-7.4 Grout Vents, Injection and Ejection Pipes: Provide all ducts or anchorage assemblies for permanent post-tensioning with pipes or other suitable connections at each end of the tendon for the injection of grout after prestressing. As a minimum, vent ducts at the high points of the tendon profile when there is more than a 6 inch [150 mm] variation in the vertical position of the duct. Use additional injection and vent pipes when shown on the shop drawings and/or in the grouting operation plan.

Make all connections to ducts with metallic or plastic structural fasteners. Use waterproof tape at all connections to include vent and grouting pipes. Ensure that vents are water tight, taped as necessary, and provide means for injection of grout through the vents and for sealing the vents.

Fit grout injection pipes with positive mechanical shut-off valves. Fit vents and ejection pipes with valves, caps or other devices capable of withstanding the grout pumping pressures.

Install all grout caps to prevent entrapment of air or water voids and to provide 100% coverage of all strands, wedges, and anchor plates in the post-tensioning anchorage.

B460-7.5 Tolerances: Ensure that post-tensioning ducts are positioned within the following tolerances:

Table of Duct Position Tolerances		
Tolerances	Vertical position Inches [mm]	Lateral position Inches [mm]
Horizontal tendons in slabs or in slab regions of larger members:	±1/4 [±6]*	±1/2 [±13]
Longitudinal draped superstructure tendons in webs:		
-tendon over supports or in middle third of span	±1/4 [±6]	±1/4 [±6]
-tendon in middle half of web depth	±1[±25]	±1/4 [±6]
Longitudinal, mostly horizontal, superstructure tendons mainly in top or bottom of member:	±1/4 [±6]	±1/2 [±13]
Horizontal tendons in substructures and foundations:	±1/2 [±13]*	±1/2 [±13]*
	Longitudinal position	Transverse position
Vertical tendons in webs	±1 [±25]	±1/4 [±6]
Vertical tendons in pier shafts	±1/2 [±13]*	±1/2 [±13]*
* nor greater than (member thickness/48) in the direction measured, whichever is less. In this context, member thickness shall be interpreted as the least thickness of concrete surrounding the tendon at the location of and in the direction of measurement.		

In all other cases or in cases of doubt, ensure that tendons are not out of position by more than ±1/4 inch [±6 mm] in any direction.

Ensure entrance and exit angles of tendon paths at anchorages and/or at faces of concrete are within ±3 degrees (±5%) of desired angle measured in any direction.

Angle changes at duct joints shall not be greater than ±3degrees (±5%) in any direction.

Locate anchorages within ±1/4 inch [±6 mm] of desired position laterally and ±1 inch [±25 mm] along the tendon except that minimum cover requirements to ends of cut off tendons and anchor components must be maintained.

Position anchorage confinement reinforcement in the form of spirals, multiple U shaped bars or links, to start within 1/2 inch [13 mm] of the back of the main anchor plate, providing the anchorage is to be encased or sealed later in the construction, and properly center around the duct.

If conflicts exist between the reinforcement and post-tensioning duct, in general, the position of the post-tensioning duct shall prevail and the adjust reinforcement shall be adjusted locally to the Engineer’s approval.

B460-8 Placing Concrete.

B460-8.1 Precautions: Exercise great care when placing and consolidating concrete so as not to displace or damage any of the post-tensioning ducts, anchorage assemblies, splices and connections, reinforcement or other embedments.

B460-8.2 Proving of Post-Tensioning Ducts: Upon completion of concrete placement, prove that the post-tensioning ducts are free and clear of any obstructions or damage and are able to accept the intended post-tensioning tendons by passing a torpedo through the ducts. Use a torpedo having the same cross-sectional shape as the duct, and be 1/4 inch [6 mm] smaller all around than the clear, nominal inside dimensions of the duct. Make no deductions to the torpedo section dimensions for tolerances allowed in the manufacture or fixing of the ducts. For straight ducts, use a torpedo at least 2 feet [0.6 m] long. For curved ducts, determine the length so that when both ends touch the outermost wall of the duct, the torpedo is 1/4 inch [6 mm] clear of the innermost wall. If the torpedo will not travel completely through the duct, the Engineer will reject the member, unless a workable repair can be made to clear the duct, all to the satisfaction of the Engineer. Pass the torpedo through the duct easily, by hand, without resorting to excessive effort or mechanical assistance.

B460-8.3 Problems and Remedies: The Engineer will reject ducts or any part of the work found to be deficient. Perform no remedial or repair work without the Engineer’s approval.

B460-9 Installing Tendons.

Push or pull post-tensioning strands through the ducts to make up a tendon. Push with care to avoid snagging on any lips or joints in the ducts. Take precautions by rounding off the end of the strand or fitting it with a smooth protective cap for this purpose.

Alternatively, strands may be assembled into the tendon and pulled through the duct together using a special steel wire sock (“Chinese finger”) or other device attached to the end. Also, the ends of the strands may be welded together for this purpose. If so, then round the end of the bundle for smooth passage and cut off and waste the entire welded end together with at least 30 inches [0.75 m] of tendon beyond the end of the last weld. Cut using an abrasive saw or similar. Flame cutting is not allowed.

When approved by the Engineer, in some special cases, such as small sized transverse tendons in the top of precast superstructure box girder segments, strands may be laid in the ducts prior to concrete placement. However, upon completion of concrete placement, the strands must be moved back and forth to ensure that they are free and unobstructed by cement grout leakage or other damage. If any such tendons are found to be unusable for stressing due to cement grout entrapment, the Engineer may reject the concrete member and seek a replacement from the Contractor at no additional cost to the Department. The time requirements for corrosion protection will commence from the time the strands were first placed in the ducts and not from the time of concrete placement, all in accordance with these Specifications. Installation of tendons in ducts prior to concrete placement is not allowed for larger sizes (i.e. seven strands, 1/2 inch [12.7 mm] diameter and larger) and longitudinal tendons in girders or cast-in-place work.

Do not install permanent tendons before the completion of testing as required by these Specifications or Plans. As a sole exception, the tendon to be tested in the “In Place Friction Test” may be installed for the test.

B460-10 Post-Tensioning Operations.

B460-10.1 General: Do not apply post-tensioning forces until the concrete has attained the specified compressive strength as determined by cylinder tests.

B460-10.2 Stressing Tendons: Tension all post-tensioning steel with hydraulic jacks so that the post-tensioning force is not less than that required by the plans or approved shop drawings, or as otherwise approved by the Engineer. Do not utilize monostrand jacks for stressing tendons with five or more strands.

B460-10.2.1 Maximum Stress at Jacking: The maximum temporary stress (jacking stress) in the post-tensioning steel shall not exceed 80% of its specified minimum ultimate tensile strength. Do not overstress tendons to achieve the expected elongation.

B460-10.2.2 Initial and Permanent Stresses: The post-tensioning steel shall be anchored at initial stresses that will result in the long term retention of permanent stresses or forces of no less than those shown on the Plans or the approved shop drawings. Unless otherwise approved by the Engineer, the initial stress after anchor set shall not exceed 70% of the specified ultimate tensile strength of the post-tensioning steel.

Permanent stress and permanent force are the stress and force remaining in the post-tensioning steel after all losses, including long term creep and shrinkage of concrete, elastic shortening of concrete, relaxation of steel, losses in the post-tensioning steel from the sequence of stressing, friction and unintentional wobble of the ducts, anchor set, friction in the anchorages and all other losses peculiar to the post-tensioning system.

B460-10.2.3 Stressing Sequence: Except as noted otherwise on the Plans, the approved shop drawings or as approved by the Engineer, permanent post-tensioning tendons must be stressed from both ends. The required force may be applied at one end and subsequently at the other end or simultaneously at both ends.

Single end stressing is permitted when the following are satisfied:

(a) Space limitations prohibit two end stressing.

(b) The calculated elongation of the post-tensioning steel at the second end is 1/2 inch [13 mm] or less.

(c) Single end stressing applied at alternate ends of paired adjacent post-tensioning tendons is required to produce a symmetrical force distribution in agreement with the Plan design.

For construction in stages where some tendons are required to be stressed before others, install and stress in accordance with the Plans or approved Shop Drawings or as otherwise approved by the Engineer.

B460-10.3 Stressing Equipment: Only use equipment furnished by the manufacturer of the post-tensioning system (tendons, hardware, anchorages, etc.).

B460-10.3.1 Stressing Jacks and Gauges: Each jack shall be equipped with a pressure gauge for determining the jacking pressure. The pressure gauge shall have an accurately reading dial at least 6 inches [150 mm] in diameter.

B460-10.3.2 Calibration of Jacks and Gauges: Each jack and its gauge shall be calibrated as a unit with the cylinder extension in the approximate position it will be in at the final jacking force. Calibration shall be done when the jack is connected to the equipment (pumps and gauges) in the identical configuration as will be used on the job site, e.g. with the same length hydraulic lines. Initial calibration of the jacks and gauges shall be performed by an independent laboratory using a proven load cell. For each jack and gauge unit used on the project, furnish certified calibration charts from the independent laboratory prior to stressing the first tendon.

Certified calibration shall be made at the start of the work and at every six months thereafter, or as requested by the Engineer. Calibrations subsequent to the initial calibration with a load cell may be accomplished by the use of a master gauge. Supply the master gauge to the Engineer in a protective waterproof container capable of protecting the calibration of the master gauge during shipment to a laboratory. Provide a quick-attach coupler next to the permanent gauge in the hydraulic lines to enable quick and easy installation of the master gauge to verify the permanent gauge readings. The master gauge will be calibrated by and remain in the possession of the Engineer for the duration of the project.

Any jack repair, such as replacing seals or changing the length of the hydraulic lines, is cause for recalibration using a load cell.

No extra compensation will be allowed for the initial or subsequent calibrations or for the use and required calibrations of the master gauge.

B460-10.4 Elongations and Agreement with Forces: Ensure that the forces being applied to the tendon and the elongation of the post-tensioning tendon can be measured at all times.

Elongations shall be measured to the nearest 1/16 inch [1.5 mm].

For the required tendon force, the observed elongation shall agree within 5% of the theoretical elongation or the entire operation shall be checked and the source of error determined and remedied to the satisfaction of the Engineer before proceeding further. Do not overstress the tendon to achieve the theoretical elongation.

In the event that agreement between the observed and theoretical elongations at the required force falls outside the acceptable tolerances, the Engineer may, at his discretion and without additional compensation to the Contractor, require additional tests for “Tendon Modulus of Elasticity” and/or “In-Place Friction” in accordance with B460-5.1 and B460-5.2.

B460-10.5 Friction: The Contract Plans were prepared based on the assumed friction and wobble coefficients and anchor set noted on the Plans. Submit calculations and show a typical tendon force diagram, after friction, wobble and anchor set losses, on the Shop Drawings based upon the expected actual coefficients and values for the post-tensioning system to be used. Show these coefficients and values on the Shop Drawings.

If, in the opinion of the Engineer, the actual friction significantly varies from the expected friction, revise post-tensioning operations so the final tendon force is in agreement with the Plans.

When friction must be reduced, water soluble oil or graphite may be used as a lubricant, subject to the approval of the Engineer. Flush lubricants from the duct as soon as possible after stressing is completed by use of water pressure. Flush these ducts again just before the grouting operations. Each time ducts are flushed, immediately blow dry with oil-free air.

B460-10.6 Wire Failures in Post-Tensioning Tendons: Multi strand post-tensioning tendons having wires which failed by breaking or slippage during stressing may be accepted provided the following conditions are met:

(a) The completed structure must have a final post-tensioning force of at least 98% of the design total post-tensioning force.

(b) For precast or cast-in-place segmental construction and for any similar construction that has members post-tensioned together across a common joint face, at any stage of erection, the post-tensioning force across a mating joint must be at least 98% of the post-tensioning required for that mating joint for that stage of erection.

(c) Any single tendon must be no more than a 5% reduction in cross-sectional area of post-tensioning steel due to wire failure.

As an exception, any of the above conditions may be waived as approved by the Engineer, when conditions permit the Contractor to propose acceptable alternative means of restoring the post-tensioning force lost due to wire failure.

B460-10.7 Cutting of Post-Tensioning Steel: Cut post-tensioning steel by an abrasive saw within 3/4 to 1 1/2 inches [20 to 40 mm] away from the anchoring device. Flame cutting of post-tensioning steel is not allowed.

B460-10.8 Record of Stressing Operations: Keep a record of the following post-tensioning operations for each tendon installed:

(a) Project name, number.
(b) Contractor and/or subcontractor.
(c) Tendon location, size and type.
(d) Date tendon was first installed in ducts.
(e) Coil/reel number for strands or wires and heat number for bars and wire.
(f) Assumed and actual cross-sectional area.
(g) Assumed and actual Modulus of elasticity.
(h) Date Stressed.
(i) Jack and Gauge numbers per end of tendon.
(j) Required jacking force.
(k) Gauge pressures.
(l) Elongations (anticipated and actual).
(m) Anchor sets (anticipated and actual).
(n) Stressing sequence (i.e. tendons before and after this).
(o) Stressing mode (one end/ two ends/ simultaneous).
(p) Witnesses to stressing operation (Contractor and inspector).
(q) Date grouted, days from stressing to grouting, grouting pressure applied and injection end.

Record any other relevant information and all repair procedures and details. Provide the Engineer with a complete copy of all stressing and grouting operations.

B460-11 Grouting Operations.

B460-11.1 General: All grouting operations shall be carried out by experienced superintendents and foremen that have received instructional training and have at least three years of experience on previous projects involving grouting of similar type and magnitude.

Submit a grouting operation plan for approval at least 45 days in advance of any scheduled grouting operations. Written approval of the grouting operation plan by the Engineer is required before any grouting of the permanent structure takes place.

At a minimum, provide the following items in the grouting operation plan:

(a) Provide names, training and experience records for the grouting crew and the crew supervisor in conformance with this Specification.

(b) type, quantity, and brand of materials used in grouting including all certifications required.

(c) type of equipment furnished, including capacity in relation to demand and working condition, as well as back-up equipment and spare parts;

(d) general grouting procedure;

(e) duct repair procedures;

(f) method(s) for sealing ducts at all connections, vents, splices, etc.;

(g) method to be used to control the rate of flow within ducts;

(h) theoretical grout volume calculations;

(i) types and locations of inlet and outlet pipes;

(j) duct cleaning methods prior to grouting;

(k) mixing and pumping procedures;

(l) direction of grouting;

(m) sequence of use of the inlets and outlet pipes;

(n) procedures for handling blockages, including flushing of ducts;

(o) method(s) to inspect behind anchorages;

(p) procedures for post grouting repair of any grout voids detected in the post-tensioning system.

Before grouting operations begin, a joint meeting of the Contractor, contractors grouting crew, grout manufacturer’s field representative and the Engineer will be conducted to discuss the grouting operation plan, required testing, corrective procedures and any other issues requested by the Engineer.

Within 30 calendar days after installation of the post-tensioning steel, grout the ducts in accordance with these Specifications. Except when approved by the Engineer in writing, failure to grout tendons within 30 calendar days will result in stoppage of the affected work and no invoices will be processed for payment of that affected work. Have the grout manufacturer’s field representative on site to witness the initial grouting operation and to provide technical assistance to the grouting crew.

Within 4 hours after stressing and prior to grouting, protect tendons against corrosion or harmful effects of debris, by temporarily plugging or sealing all openings and vents. Within this period, clean rust and other debris from all metal surfaces which will be covered by the grout cap and place the permanent non-metallic grout cap, including a seal, over the wedge plate until the tendon is grouted.

When stressing has been completed and the stressed tendons have been accepted by the Engineer, grout the annular space between the tendons and the duct.

B460-11.2 Equipment: Use a colloidal grout mixer and pump capable of continuous mechanical mixing and producing a grout free of lumps and undispersed cement. Use equipment able to pump mixed grout in a manner complying with all the provisions specified herein. Provide accessory equipment that will provide for accurate solid and liquid measures necessary to batch all materials.

Use positive displacement type grout pumps able to produce an outlet pressure of at least 150 psi [1 MPa], with seals adequate to prevent oil, air or other foreign substances entering into the grout and to prevent loss of grout or water. Place a pressure gauge having a full scale reading of no more than 300 psi [2 MPa] at some point in the grout line between the pumping outlet and the duct inlet. The grouting equipment must contain a screen having clear openings of 0.125 inch [3.35 mm] maximum size to screen the grout prior to its introduction into the grout pump. If using grout with an additive, a screen opening of 3/16 inch [4.75 mm] is satisfactory. Ensure that this screen is easily accessible for inspection and cleaning. Utilize a gravity feed to the pump inlet from a hopper attached to and directly over it. Keep the hopper at least partially full at all times during the pumping operation to prevent air from being drawn into the post-tensioning duct. Under normal conditions, the grout equipment must be capable of continuously grouting the longest tendon on the project in not more than 20 minutes.

B460-11.3 Mixing: Mix the grout in accordance with the manufacturers instructions using a colloidal mixer to obtain a homogeneous mixture. Perform a fluidity test on the mixed grout, in accordance with Section 938, prior to beginning the injection process. Do not begin the grouting process until the proper grout properties have been obtained. Meet the specified target flow rates.

B460-11.4 Grout Injection: Open all grout vents and high point vent openings before grouting starts. Provide injection and ejection vents with positive shut-offs. Allow grout to flow from the first vent after the injection vent until any residual flushing water or entrapped air has been removed, then close that vent. Close remaining vents in sequence in the same manner. Maintain a continuous flow of grout at a rate not to exceed 30 feet [10 meters]of duct per minute.

Do not allow the pumping pressure at the injection vent to exceed 150 psi [1 MPa] for oval ducts nor 250 psi [1.7 MPa] for circular ducts, however; normal operations shall be performed at approximately 75 psi [500 kPa]. If the actual grouting pressure exceeds the maximum allowed, close the injection vent and inject the grout at the next vent which has been, or is ready to be, closed as long as a one way flow is maintained. Do not inject grout into a succeeding vent from which grout has not yet flowed.

Pump grout through the duct and continuously waste at the ejection vent until no visible slugs of water or air are ejected. Perform a fluidity test, in accordance with Section 938, on each tendon measuring the grout discharged from the discharge outlet. The measured grout efflux time shall meet the requirements of the Fluidity Test listed in Section 938. If the grout efflux time is not acceptable, discharge additional grout from the discharge outlet. Test grout efflux time. Continue this cycle until an acceptable grout fluidity is achieved. Ensure that the tendon remains filled with grout, by closing the ejection and injection vents in sequence, respectively, under pressure when the tendon duct is completely filled with grout. Do not remove the positive shut-offs at the injection and ejection vents or open until the grout has set.

B460-11.5 Temperature Restrictions: In temperatures below 32ºF [0ºC], keep ducts free of water to avoid damage due to freezing. The temperature of the concrete shall be 35ºF [2ºC] or higher from the time of grouting until job cured 2 inch [50 mm] cubes of grout reach a minimum compressive strength of 80 psi [5.5 MPa]. Grout shall not be above 90ºF [32ºC] during mixing or pumping. If necessary, cool the mixing water.

B460-11.6 Vertical Grouting: In lieu of a positive shut off, vertical or near vertical tendon ducts for grouting shall terminate in reservoirs at the upper most point. The reservoir shall have sufficient capacity to store all bleed water to enable its re-absorption into the grout. Maintain the reservoirs until the grout has set and the bleed water absorbed.

B460-11.7 Finishing: Do not remove or open valves, caps and vent pipes until the grout has set. Remove the ends of steel vents at least 1 inch [25 mm] below the concrete surface after the grout has set. Remove ends of plastic vents to the surface of the concrete after the grout has set. Remove all miscellaneous material used for sealing grout caps before carrying out further work to protect end anchorages or filling in concrete anchorage blockouts and the like. Miscellaneous materials include paper, tie wire, duct tape, etc.

B460-12 Protection of End Anchorages.

After grouting has been completed for a minimum of 72 hours, sound the permanent non-metallic grout cap covering the wedge plate to check for voids and probe, through venys or other devices, behind anchorages and grouted pockets for the presence of voids in the presence of the Engineer. Do not fill any voids or begin activities to protect the end anchorage prior to inspection by the Engineer. Upon inspection by the Engineer, fill any voids detected using methods approved by the Engineer. Within 54 hours after grout cap inspection, clean exposed areas of end anchorages and other metal accessories of rust, misplaced mortar, grout and other such materials. Immediately following the cleaning operation, install tight fitting forms and hold in place securely against the previously placed concrete. Fill the void between the form and the anchorage with an epoxy grout meeting the requirements of API (American Petroleum Institute) Specification 610-Appendix L, 1995 to protect the anchorage. As an option, anchorages inside segmental box structures, other than on the face of diaphragms adjacent to expansion joints, may be encased with concrete of the same class as required for the segment after the application of an epoxy bonding compound meeting the requirements of AASHTO M 235, Class III. Place the concrete within the "tack time" period of the epoxy bonding agent/compound. Accomplish all work described in this and the preceding paragraph within the designated 54 hour time period.

After the anchorage encasement material has been properly cured, and within 4 hours of the form removal, apply two heavy brush coats of bituminous protective coating material meeting AASHTO M 115 in a manner and thickness recommended by the manufacturer. Apply the bituminous protective coating only to anchorages which are not exposed to the exterior of the structure or where further concrete encasement does not occur.

B460-13 Method of Measurement.

The quantity of post-tensioning tendons to be paid for under this Section will be the computed weight, in pounds [kilograms], of permanent post-tensioning steel tendons entered into the completed structure and accepted. Measurement will be the theoretical plan length measured from anchor plate bearing face to anchor plate bearing face with no allowance made for waste or extension past the anchor plate faces. No measurement will be made for temporary post-tensioning which will be considered incidental to the item "Post-Tensioning Tendons".

For quantity determination, the following unit weights will be used:

Prestressing System	Weight per Unit Length (b/ft [kg/m])
1/2 inch [12.7 mm] diameter seven wire strand	0.52 [0.77]
0.6 inch [15.2 mm] diameter seven wire strand	0.74 [1.1]
1 inch [26 mm] high strength deformed bar	3.01 [4.48]
1 1/4 inch [32 mm] high strength deformed bar	4.39 [6.54]
1 3/8 inch [36 mm] high strength deformed bar	5.56 [8.28]

B460-14 Basis of Payment.

B460-14.1 General: Post-tensioning tendons will be paid for at the Contract unit price per pound [kilogram] of steel tendon, complete and in place. Payment will be full compensation for furnishing, installing, stressing and grouting all temporary and permanent post-tensioning tendons. Payment also includes anchorage assemblies and post-tensioning system hardware which is not embedded in concrete, external ducts, grout and grouting, all testing, anchorage protection systems and all labor, materials, tools, equipment and incidentals necessary for completing the work in accordance with these Specifications and the Plans. This payment also includes lubricants in the tendon ducts for friction control and flushing the lubricant from the tendon ducts after stressing. No separate measurement and payment will be made for anchorage components, local anchorage zone reinforcement supplied as an integral part of a proprietary anchorage system, nor ducts for similar post-tensioning system hardware. Anchorage components, ducts and similar items of post-tensioning system hardware embedded within precast components or cast-in-place concrete will be deemed to be included in the cost of the precast components or cast-in-place concrete.

B460-14.2 Payment Items:

Payment will be made under:

Item No. 460-111- Post-Tensioning Tendons - per pound.
Item No. 2460-111- Post-Tensioning Tendons - per kilogram.

If the Contractor constructs the structure with an accepted alternate not detailed on the Plans, payment will be based on the unit price bid extended by either the quantities shown on the Plans or the actual quantities used and accepted, whichever is less.

Permanent post-tensioning strand or bar tendons which are an integral part of individual precast concrete segments or units will be measured and paid for under this item and will not be considered incidental to the cost of those precast concrete segments or units.

Payment for post-tensioning will be made following successful placement, stressing, grouting and approval by the Engineer. Full payment for post-tensioning tendons, within precast segmental concrete structure units, may occur prior to erection of the segments into their final position when ducts have been grouted and the segmental unit otherwise approved for placement by the Engineer.